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Visual Motion Processing in One-month-old Infants: Habituation Experiments

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The ability of infants to discriminate between opposite directions of motion was examined in infant control habituation experiments. A group of 3–5-week-olds showed no evidence of discrimination between a random-dot pattern which was segregated into regions that moved in opposite directions, and a uniform pattern in which the dots all moved in the same direction. However, they did discriminate between segregated and uniform patterns in two additional conditions, neither of which required sensitivity to direction: in the first of these, segregation was based on the contrast between coherently moving and stationary dots, while in the second the contrast was between coherently and incoherently moving dots. Unlike the younger infants, a slightly older group of 6–8-week-olds proved capable of discriminating between the segregated and uniform patterns when the contrast was between opposite directions of motion. These results confirm and extend the results from preferential looking [Wattam-Bell, J. (1996). Motion processing in one-month-old infants: Preferential looking experiments. *Vision Research*, *36*, 1671–1677]; they suggest that direction discrimination may not emerge until around 6–8 weeks of age. The apparent lack of direction discrimination before 6 weeks may reflect an inability to use directional cues to visually segment the segregated pattern, rather than an insensitivity to direction as such. To examine this, a further set of infants was tested for absolute direction discrimination—i.e., between leftwards- and rightwards-moving uniform patterns. However, in this case neither 3–5- nor 6–8-week-olds showed any evidence of discrimination, which suggests that direction discrimination may first emerge for relative motion. Possible reasons for this are discussed. Copyright © 1996 Elsevier Science Ltd.

Visual development   Visual motion processing   Direction discrimination

INTRODUCTION

The forced-choice preferential looking (FPL) experiments of Wattam-Bell (1996) found no evidence that 1-month-old infants could discriminate between a random-dot pattern in which dots in adjacent regions moved in opposite directions (segregated pattern), and one in which all the dots moved in the same direction (uniform pattern). This suggests that 1-month-olds may not be sensitive to the direction of visual motion. However, other interpretations cannot be excluded. FPL depends on an intrinsic visual preference for one of the patterns, such as that shown by older infants, who prefer the segregated one (Wattam-Bell, 1992). While the presence of a preference implies discrimination, which in turn implies sensitivity to direction, direction sensitivity need not necessarily be reflected in a preference.

Habituation experiments offer a means of exploring visual discriminations in infancy which does not rely on intrinsic preferences. The method has been used successfully with infants of all ages, and for a variety of discriminations, including cases where an intrinsic preference is most unlikely—for example, the demonstration that newborns can distinguish between gratings oriented at 45 and 135 deg (Slater *et al.*, 1988; Atkinson *et al.*, 1988). This paper describes habituation experiments on 1- and 1½-month-olds which re-examine discrimination between the segregated and uniform patterns tested in the FPL experiments (Wattam-Bell, 1996). The same three conditions were used: opposite directions of motion (see above); moving vs static, for which the segregated pattern was divided into coherently moving and stationary regions, and the uniform pattern was stationary; and coherent vs incoherent motion, for which the segregation was between coherently and incoherently moving regions, and the uniform pattern moved incoherently.

The last two discriminations do not demand the use of information about the direction of motion (see Wattam-Bell, 1996), and so are quite likely to be possible for subjects who lack directionality. The FPL results suggest that this may be the case with 1-month-olds. They performed at chance in the direction discrimination task, but showed a clear preference for the segregated pattern in the other two. One reason for this might be that a preference for the segregated pattern only occurs when

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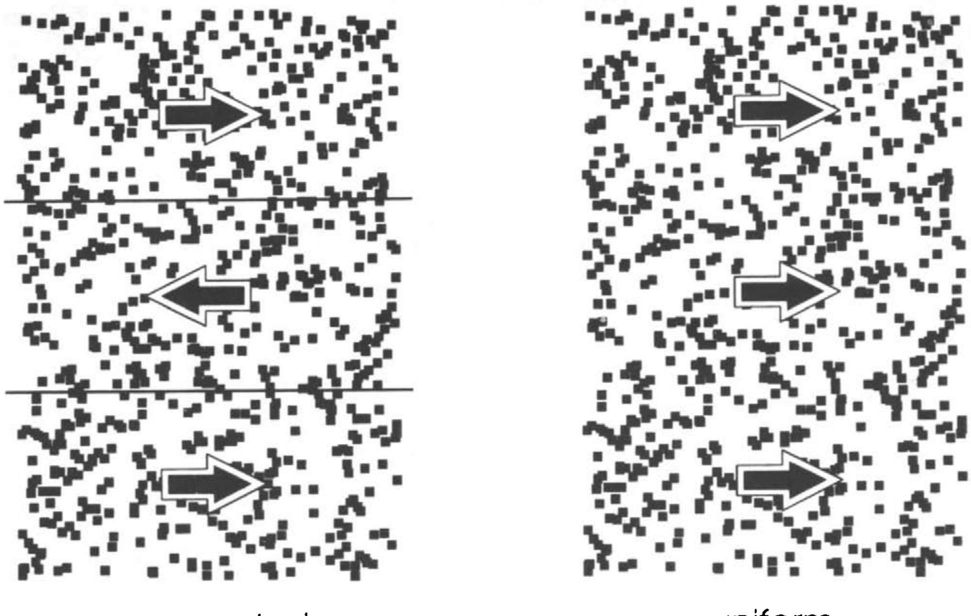

FIGURE 1. Schematic of the random-dot patterns. Each pattern was made up of 768 bright (14.3 cd/m^2) square elements drawn on a dark (0.9 cd/m^2) background (note that contrast is reversed in this figure). Average density was 1.35 elements/deg^2: each element measured 0.48×0.48 deg, so that the elements covered 31% of the area of each pattern. The three regions of the segregated pattern were each 10 deg high.

the visual system succeeds in segmenting it. Perhaps 1-month-olds, although sensitive to direction, are unable to use directional cues for image segmentation, while they can use the non-directional cues available in the other two conditions. If this is the case, then these infants might still be capable of absolute direction discrimination—e.g. between a uniform pattern moving leftwards and one moving rightwards. The final experiment reported here examined this.

METHODS

Stimuli

The stimuli were random-dot patterns, as illustrated in Fig. 1. Each pattern consisted of 768 bright squares placed randomly within a 19 deg wide by 30 deg high rectangular region of the otherwise dark screen. The patterns could be static, or they could move either coherently along the horizontal axis (the elements were displaced by the same distance, and in the same direction, between successive frames of the display), or incoherently (each element was randomly repositioned between successive frames). In addition, a pattern could be uniform—all elements undergoing the same kind of motion—or segregated horizontally into three 10 deg high regions, with the central region moving differently to the upper and lower regions. Figure 1 illustrates the case where segregation is based on opposite directions of coherent motion. In the present experiments, the habituation pattern was always uniform.

The patterns were generated by an Acorn Archimedes computer and displayed on a 26" video monitor (Mistsubishi HC3505). The computer updated the display every 20 msec; the coherent motion consisted of a sequence of discrete displacements separated by this interval, and had a velocity of 50× (displacement size). The computer drew the patterns on an underlying pixel array whose pitch was 0.08 deg, and this was the smallest distance that an element could move between successive frames; hence the minimum velocity of coherent motion was 4 deg/sec.

Procedure

The experiments used an infant control habituation procedure (Horowitz, 1975), followed by two test trials in which the novel and habituation stimuli were presented simultaneously: simultaneous presentation has been shown to improve the sensitivity of the habituation method for other discriminations by 1-month-olds and younger infants (Slater *et al.*, 1988; Atkinson *et al.*, 1988). For the habituation trials, the stimulus was a single random-dot pattern displayed in the centre of the screen, and was always the uniform member of a uniform/segregated pattern pair. At the start of a trial the infant was turned to face the screen, which was blank apart from a central fixation stimulus. The observer waited until the infant was looking at this before pressing a button to start the trial proper; the computer then removed the fixation mark and displayed the habituation stimulus. Looks away from, and back to, this stimulus were recorded by further button presses, and the trial continued until the first look away that lasted >2 sec. The infant was turned away from the screen for a short period (about 5 sec) and then turned back for the next trial. For each trial the computer recorded the total time that the infant spent actually looking at the stimulus. It also calculated the mean looking time of each possible set of three consecutive trials, and the habituation phase continued until this mean time had fallen to 50% or less of its previous peak value, with the proviso that these last three trials did not overlap with the three contributing to the peak. Once this criterion had been reached the test phase started. Test trial procedure was similar to the habituation trials, but now the display contained the habituation stimulus on one side, and the novel stimulus on the other; they were placed symmetrically about the midline of the screen, with their inner edges separated by 10.2 deg. The observer's button presses recorded the onset of looks towards either of the two patterns, or away from both. The trial continued until total time spent looking at the stimuli reached 20 sec. There were two test trials; in the first the location of the habituation and novel stimuli were chosen at random while in the second their positions were reversed.

The results were expressed as the percentage of the total looking time for which the infant looked at the novel stimulus over both test trials; thus a value of >50% implies a preference for the novel stimulus.

The infants sat on a holder's lap at a distance of 40 cm from the display, which was surrounded by grey card, and beyond this by grey curtain. Room lighting was adjusted so that the luminance of the display and surround were similar. The observer viewed the infant from behind the display through a small hole immediately above the centre of the monitor, and could not therefore see the screen.

Subjects

The infant subjects were born within 14 days of their expected date, and had no known ocular or other medical problems. Two age groups were tested: 3–5-week-olds and 6–8-week-olds. All ages are reported as weeks post-term, and are exact in the sense that, for example, a group of 3–5-week-olds included only infants aged between 3 weeks 0 days and 5 weeks 6 days.

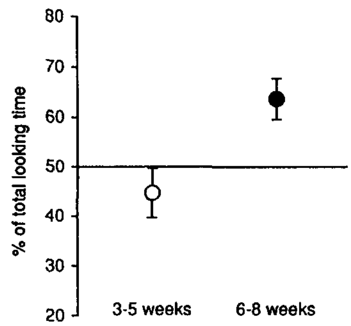

FIGURE 2. Results of Experiment 1 on direction discrimination for relative motion. They are plotted as mean values (± 1 SE) of the per cent of total looking time that the infants spent looking at the segregated pattern over both test trials. The test trials were preceded by habituation to the uniform pattern; thus the segregated pattern was also the novel one here. In this and the following figures, results that were significantly different from 50% (two-tailed t-test, $P < 0.05$) are plotted with solid symbols, while open symbols are used for results that were not significant.

EXPERIMENT 1

This experiment tested direction discrimination with the stimuli illustrated in Fig. 1. The central panel of the segregated pattern moved in the opposite direction to the upper and lower panels, while in the uniform pattern all the dots moved in the same direction. All the dots moved horizontally, but every 0.48 sec their direction reversed from leftwards to rightwards or vice versa. This happened simultaneously everywhere in the stimulus, so the segregated pattern remained segregated into regions of opposite directions, and the uniform pattern remained uniform.

It is clear from the FPL results of Wattam-Bell (1996) that the velocity of the coherent motion is likely to be critical when testing 1-month-olds. Unfortunately the habituation procedure is too long-winded to allow separate tests at a number of different velocities. Instead, the infants were tested with displays containing a range of different velocities simultaneously. Each region of coherent motion contained a mixture of equal numbers of dots moving at one of three velocities; for adult observers this resulted in the appearance of three superimposed transparent planes drifting at different speeds. The speed of an individual dot was constant during a trial, and was not correlated with its initial position. The three velocities were 8, 12 and 16 deg/sec. They were chosen to cover the lower end of the velocity range which gave above-chance FPL performance in the coherent vs static and coherent vs incoherent conditions (see Wattam-Bell, 1996). The high end of this range was avoided because in all older subjects its upper limit (d_{max} for coherent vs incoherent motion) is some three times the upper limit for direction discrimination (Wattam-Bell, 1992).

The infants were habituated to uniform motion (i.e. the right side of Fig. 1), so that in the test phase the novel stimulus was always the segregated one (left side of Fig. 1). The alternative sequence, in which the uniform motion is the novel stimulus, could also have been used, but in this case any intrinsic preference for the segregated stimulus could undermine the effect of habituation. Clearly if there is any intrinsic preference it is very weak, but given the behaviour of older infants it is most likely to be in favour of the segregated stimulus. On balance it seemed that habituating to uniform motion, thus allowing habituation and preference to combine forces, was most likely to reveal clear evidence of direction discrimination.

Results

Fifteen 3–5-week-olds (mean age 4.8 weeks) and nine 6–8-week-olds (mean age 7.5 weeks) contributed to the results, which are plotted in Fig. 2. In this and subsequent figures, the results are shown as the proportion of the total test trial time for which the infants looked at the novel stimulus. For the 3–5-week-olds, this was not significantly different from 50% ($t = 1.14$, $P > 0.2$, two-tailed);

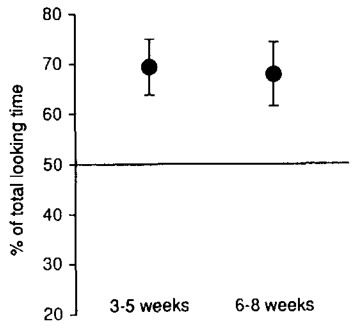

FIGURE 3. Results for the moving vs static condition of Experiment 2, plotted as the mean (±1 SE) percentage of the total test trial time for which the infants looked at the segregated pattern. The test trials were not preceded by habituation, so a significant result here implies an intrinsic preference.

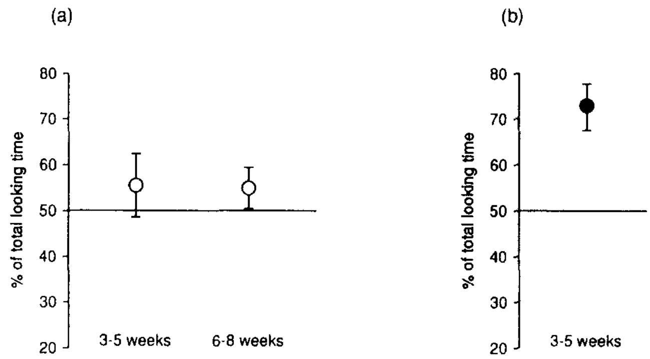

FIGURE 4. Results for the coherent vs incoherent condition of Experiment 2, plotted as the mean (±1 SE) percentage of the total test trial time for which the infants looked at the segregated pattern. (a) Results from the infants given the test trials only, without prior habituation. (b) Results from infants who were habituated to the uniform (incoherent) pattern before the test trials, so that the segregated pattern was also the novel one. Only 3–5-week-olds were tested.

they distributed their looking-time more-or-less equally between the old and new patterns. The 6–8-week-olds, on the other hand, looked for significantly longer at the novel (segregated) stimulus ($t = 3.36$, $P < 0.01$). In this experiment, the older infants showed evidence of direction discrimination, but the younger infants did not.

EXPERIMENT 2

The results of the 3–5-week-olds in Experiment 1 agree with the FPL results from 3–6-week-olds (Wattam-Bell, 1996); younger infants appear unable to use directional cues to discriminate between the segregated and uniform patterns. However, in the FPL experiments the infants proved capable of discriminating between segregated and uniform patterns under two additional conditions in which non-directional cues were available. The next experiment sought to confirm that infants could do these non-directional discriminations with the somewhat different stimuli used in the present experiments. The two conditions tested were:

(a) Moving vs static. The central region of the segregated pattern moved coherently, while the upper and lower regions, and the uniform pattern were all stationary.

(b) Coherent vs incoherent motion. The central region of the segregated pattern again moved coherently, but the upper and lower regions and the uniform pattern moved incoherently (see Methods).

In each case the coherent region moved horizontally with direction reversals every 0.48 sec, and consisted of equal numbers of dots moving at 8, 12 and 16 deg/sec.

The test phase of the habituation procedure is a form of preferential looking in which preference is determined from the relative amount of time spent looking at each of the stimuli in the course of two 20 sec trials. With the full habituation procedure, the aim is to induce a preference for one stimulus by first habituating the infant to the other. However, the FPL results suggest that infants will show an intrinsic preference for the segregated pattern in both conditions tested in this experiment. So the infants were initially given the test trials only, without prior habituation to one of the patterns. This procedure produced the expected preference in the moving vs static condition, but not in the coherent vs incoherent task: so a further group of infants was tested for the latter discrimination with the full habituation method.

The subjects of this experiment were a subset of the infants tested in Experiment 1. Each did the direction discrimination task (Experiment 1) first, while the order of the other two conditions was counterbalanced across subjects.

Results

Figure 3 shows the results for the moving vs static condition (test trials only) from ten 3–5-week-old and eight 6–8-week-olds. Both age groups fixated the segregated pattern for significantly >50% of the total time (3–5 weeks: $t = 3.5$, $P < 0.01$; 6–8 weeks: $t = 2.62$, $P < 0.02$), thus showing the expected intrinsic preference.

For the coherent vs incoherent task, eight infants in each age group were tested without prior habituation. Their results are shown in Fig. 4(a); although both groups looked slightly longer at the segregated pattern, this preference was not significant in either group (3–5 weeks: $t = 0.70$, $P > 0.4$; 6–8 weeks: $t = 1.02$, $P > 0.3$).

A further five 3–5-week-olds were tested with the coherent vs incoherent condition, but this time they were habituated to the uniform (incoherent) pattern before the test trials. These infants, whose results are plotted in Fig. 4(b), showed a significant preference for the novel, segregated pattern ($t = 4.45$, $P < 0.02$). Six to eight week-olds were not tested with the full habituation procedure.

The absence of a preference in the coherent vs incoherent task, when the infants were given only the test trials, indicates that the distribution of looking time over two trials is a less robust way of revealing intrinsic preferences than per cent preference over 10 or more trials, as used in the previous FPL experiments (Wattam-

Bell, 1996). In the FPL experiments, preference for the segregated pattern was stronger in the moving vs static condition than in the coherent vs incoherent condition: this may be the reason why the looking-time measures in the present experiment only revealed an intrinsic preference with the moving vs static task.

EXPERIMENT 3

While the results of the previous experiments suggest that sensitivity to direction emerges at around 6 weeks, there is another possibility: it may be that what is emerging is the ability to use directional information for image segmentation, which might develop later than the underlying directional selectivity. Discrimination of absolute direction (e.g. leftwards vs rightwards motion) should provide the most unambiguous evidence for directional selectivity. The next experiment examined this discrimination, again using habituation. Certain problems were anticipated with this experiment; the continuous unidirectional motion of the stimuli is likely to generate significant OKN which could make it impossible for the observer to remain ignorant about which stimulus the infant was viewing. Moreover the OKN would make it hard to interpret a positive result; is discrimination based on cortical directional responses, or on feedback from the eye movements, in which case cortical directionality may be unnecessary? In practice, only short bursts of OKN were seen, and it was much less prevalent than expected, particularly in the younger infants. When present in the test trials it did not cause any ambiguity about which side of the display the infant was fixating, and it was surprisingly hard to decide whether or not it was in the same direction as any OKN seen during the habituation trials.

The stimuli were uniform patterns which moved coherently either leftwards or rightwards, without direction reversals. Infants were habituated to one of the directions, and then tested with leftwards motion on one side of the display, and rightwards on the other; as before, the sides were chosen randomly for the first test trial, and swapped for the second. Discrimination was tested with two kinds of motion: the simultaneous mixture of three velocities (8, 12 and 16 deg/sec) used before, and a single velocity (12 deg/sec). In addition, both directions of motion were used as habituation stimuli. Of the four possible conditions, two were attempted with each infant; in the second run both the type of motion, and the direction of motion in the habituation phase were changed.

Results

Results were obtained from nineteen 3–5-week-olds (mean age 4.5 weeks), with 12 completing two runs while the rest managed only one; and twenty-one 6–8-week-olds (mean 7.6 weeks), nine of whom completed two runs. The results were combined across the different habituation directions, but kept separate for the different types of motion. They are shown in Fig. 5. Neither age group showed a significant preference for the novel stimulus in either the single- or multiple-velocity conditions; these infants gave no evidence for absolute direction discrimination in this experiment.

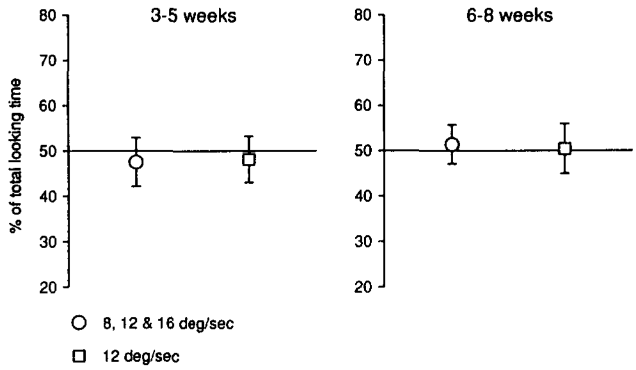

FIGURE 5. Results of Experiment 3 on absolute direction discrimination. They are plotted as the mean percentage (±1 SE) of the total test trial time for which the infants looked at the novel direction. Circles: single velocity (12 deg/sec). Squares: three simultaneous velocities (8, 12 and 16 deg/sec).

DISCUSSION

The 3–5-week-olds showed no evidence that they could use information about direction of motion to discriminate between the segregated and uniform patterns of Experiment 1: but they did discriminate between segregated and uniform patterns when non-directional cues were available—in the moving vs static and coherent vs incoherent conditions of Experiment 2. This is the same pattern of results as that shown by 3–6-week-olds tested with FPL (Wattam-Bell, 1996). In contrast to this, the slightly older 6–8-week-olds showed clear evidence of direction discrimination in Experiment 1. Perhaps the most obvious interpretation of these results is that 1-month-old infants are not sensitive to the direction of motion, and that this sensitivity emerges at about 7 weeks.

However, it remains possible that the stimuli did not contain exactly the right velocities; perhaps sensitivity to direction is present at 3–5 weeks, but is confined to only one of the velocities used in the multiple-velocity conditions, so that the others act as noise, masking the velocity to which the infants are sensitive, and reducing discriminability. Multiple velocity stimuli may not be the best way of dealing with the problem of finding the right velocity for testing infants' directionality: nevertheless, the 6–8-week-olds coped admirably with these stimuli, indicating a marked improvement in direction discrimination between the two age groups. The results point to the same conclusion as the FPL study—that if there is any sensitivity to direction before about 7 weeks, it is confined to a very narrow range of velocities, perhaps narrower than the inter-individual differences in the location of this range, which would make it difficult to pin down experimentally. Moreover, the majority of visual motions in everyday experience will fall outside this range and will not be directionally coded: it still seems reasonable to characterise 1-month-olds as essentially 'direction-blind'.

Directionally selective mechanisms must be present in the very young infant's visual system: even newborns produce optokinetic nystagmus (OKN) in the appropriate direction. However OKN is probably a subcortical reflex at birth (Atkinson & Braddick, 1981; Hoffmann, 1987), mediated by pathways which are unlikely to be directly involved in perception. Cortical pathways are involved in smooth pursuit and, insofar as it can be distinguished empirically from OKN, the available evidence suggests that pursuit is not reliably seen before about 7 weeks (Aslin, 1981). This agrees well with the onset of direction discrimination suggested by the present results, though the caveat about choosing the right velocity may well apply equally to both measures (see Shea & Aslin, 1990).

Directional mechanisms are also likely to be involved in the blink response to expanding visual stimuli. van Hof-van Duin and Mohn (1986) found that this response first appears at about 2–3 months of age, though Yonas & Granrud (1985) report that it can occasionally be seen in 1-month-olds. These findings suggest that in the majority of infants, this directional response appears shortly after 1 month of age, which is compatible with the onset of directionality found here.

In Experiment 3, neither age group showed evidence of absolute direction discrimination. This result lends support to the idea that the younger infants lack sensitivity to direction: but the older infants' failure to discriminate absolute direction, when contrasted with their success with relative motion in Experiment 1, seems paradoxical. One possibility, that the 6–8-week-olds tested in Experiment 3 were rather immature, can probably be ruled out, since more recent habituation experiments in our laboratory have failed to produce robust evidence for absolute direction discrimination in 8–12-week-olds (Braddick *et al.*, 1994).

A closer examination of the tasks involved in the two types of direction discrimination sheds some light on this. First, detection of the relative motion in the segregated pattern can be done by local comparisons of the activity of neighbouring first-order directional mechanism. This is a second-order process, whose output must register that there are places in the pattern where adjacent parts are moving in different directions, and this can be used to segment the pattern: but information about the actual directions involved does not need to be preserved at this stage (in practice it might help if it is not, since it changes with every direction reversal).

For absolute direction discrimination, direction information does need to be retained. Moreover, measurements of direction require a reference external to the stimulus. Distant landmarks like the edge of the screen could be used, which would involve global comparisons between unconnected parts of the visual field. Alternatively, the retinal mosaic could act as the reference; direction could be judged directly from measures of retinal image motion. In general, however, eye and body movements alter the relationship between the physical motion of an object and the resulting retinal image motion; so accurate measurement of physical motion requires additional information about bodily movements. Generally speaking, the relationship between the speeds of the physical and retinal image motions will be more variable than that between directions, but the latter will be affected.

The discussion of the last two paragraphs suggests two alternative accounts for the paradoxical direction discrimination performance of 6–8-week-olds:

1. directional responses can be used to detect relative motion between adjacent locations, but information about direction is not preserved beyond this, and so is not available for absolute direction discrimination;
2. directional information can in principle be retained, but under the conditions of the absolute direction task infants are forced to rely solely on local measurements of retinal image motion, and by itself this information is too uncertain to support discrimination.

In other words, the infants may be unable to make global comparisons between local motion signals arising from distant parts of the visual field, or to combine information about eye and body movements (proprioception or efference copy) with measures of image motion.

One way of approaching the question of whether information about direction is preserved would be to re-examine absolute (left vs right) direction discrimination with stimuli containing an internal reference—regions of stationary dots. Such experiments are currently in progress.

If it is the case that no amount of stimulus refinement will produce evidence for direction discrimination by infants younger than 6 weeks in these kinds of experiments, would it be fair to conclude that younger infants lack cortical directional selectivity? The discussion above suggests it would not; perceptual discrimination of direction may appear first for (locally) relative motions, and must wait on the development of the appropriate organisation (i.e. second order comparisons) of the outputs of directional mechanisms. Cortical directionality may be present at birth in humans, as it is in kittens (Albus & Wolf, 1984). There are indirect ways of testing this, for example the motion VEPs of Norcia *et al.* (1991); 2-month-olds show a monocular VEP asymmetry, which Norcia *et al.* suggest reflects an underlying asymmetry of cortical directionality. However, there are not enough data available yet to be certain that the asymmetry is consistently present before 6 weeks. An alternative approach is that used by Dobkins and Teller (1994); they demonstrated that at some velocities, 3-month-olds use directional mechanisms to detect contrast. If methods like these can reveal cortical directionality at birth, then perhaps infants go through an apparently paradoxical phase in which they can use directional mechanisms for detection, but are unable to discriminate between different directions; the labels (but not the responses) of directional mechanisms get lost somewhere *en route* between stimulus and behaviour.

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